Topographic Influence on Internal Waves and Mesoscale Oceanic Dynamics

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Grant Number: N000149710140
http://www.eas.asu.edu/~pefdhome and http://ceaspub.eas.asu.edu/oceanrus

LONG TERM GOAL

The long-term goal of our research is to identify and quantify key processes responsible for small-scale mixing in oceans and to evaluate basin-averaged turbulent diffusivities akin to such processes. Recently, particular attention was given to quantify topographically induced oceanic mixing.

OBJECTIVES

The primary objective of the project is to conduct a comprehensive analysis on small and mesoscale phenomena at selected oceanic sites influenced by topography. Mixing, internal waves and eddies are of major concern during this work. During the last year, we focused on the development of a web-accessible database of mooring and profiling measurements taken by Russian oceanographers in deep basins of the Atlantic, Pacific, and Indian oceans and in the marginal seas of western Pacific. Collecting of new oceanographic measurements on mesoscale ocean dynamics was of major concern in our work. We continued research on (i) the decay of tidal internal-wave energy away from submarine ridges, (ii) the formation and evolution of tidally-induced bottom boundary layer and (iii) mixing at shallow shelves.

APPROACH

We analyzed existing measurements of microstructure and internal waves influenced by topography, conducted numerical modeling on the development of fine structure in the bottom boundary layer, and carried out new measurements of thermohaline structure and currents in the North and Equatorial Atlantic. The work involved substantial collaboration with Russian oceanographers. New CTD and ADCP measurements were taken at two trans-Atlantic sections during two research cruises organized by the P.P. Shirshov Institute of Oceanology Russian Academy of Sciences. Dr. Alexander Ksenofontov was closely involved in numerical modeling of the near-bottom turbulence affected by tidal flows; Dr. Eugene Morozov extended and modified the mooring database.

WORK COMPLETED

A web-accessible version of the mooring database of the P.P. Shirshov Institute of Oceanology was created. The data are sorted out by the year, name of the experiment and geographical region. The access to data is available via a clicking map. Profiling CTD measurements and mooring data from the

South China Sea, Japanese Sea and Okhotsk Sea were prepared by Dr. V. Navrotsky (FarEast Institute of Oceanology, Vladivostok) and are now available at the project web page. The data can be downloaded via the EFDP website.

We completed a study on vertical mixing on the shallow shelf of the Black Sea (Lozovatsky and Fernando 2000). In addition to previous findings (Lozovatsky et al. 1999, Lozovatsky and Fernando 1999) we investigated the dependence of Thorpe scale in stratified turbulent patches on patch Richardson number and mixing Reynolds number. We also calculated the vertical diffusivity K for various layers and obtained an averaged estimate of K for the entire water column on the shelf, in the range of $(9\text{-}11)\times10^{-5}$ m^2/s.

The amount of energy of internal tides generated by the barotropic tide at the Mascarene ridge was estimated. It was found that the baroclinic tidal energy decreases to the barotropic level at a distance of about 11 wavelengths of the first mode of semidiurnal tidal internal wave. A short version of the results on this study has been published (Lozovatsky et al. 2000a) and the extended version of the paper is under preparation.

Our model of the near-bottom stratified turbulent boundary layer (Lozovatsky and Ksenofontov 1998) was reformulated to include direct influence of the bottom stress (via parameterisation of bottom roughness) and boundary turbulent flux. This allowed simulating of fine structure in the near bottom pycnocline, correctly adjusted to account for the mean flows.

Two cruises in the Atlantic Ocean were completed onboard of r/v Akademik S. Vavilov (October-November 1999, chief scientist Dr. S. Shapovalov) and r/v Akadimik Ioffe (June-August, 2000, chief scientist Dr. A. Sokov) with participation of one of the PIs (I. Lozovatsky). Fifty seven CDT stations along 48^0N were taken from the sea surface to the very bottom during the 1999 cruise. In 2000, sixty one CTD stations were obtained between coastal zones of Guinea and Brazil, approximately along 6^0N. The last data are accompanied by ADCP measurements in the upper 600 m layer. Data of both cruises are preprocessed and will be analyzed to address ageostrophic component of the upper layer and the influence of fine structure processes on the transformation of water masses in marginal zones.

RESULTS

A. *The decay of energy in tidal internal waves downstream of a submarine ridge*

The highly energetic barotropic tide observed near the Mascarene Ridge in the Indian Ocean generates intense tidal internal waves that propagate away from the ridge in the northwest - southeast direction. The wavelength of the first internal mode is λ = 140-150 km. We analyzed variations of the kinetic E_k and potential E_p energies of internal tide as a function of the normalized distance x/λ from the ridge (Fig. 1). As the distance from the ridge grows, from 0.6 to about 10 tidal wavelengths, KE decreases almost ten times in amplitude over the entire pycnocline (Fig. 1a). A general decrease in amplitude downstream of the ridge is also evident in E_p (Fig. 1b), but PE is more depth-dependent compared to KE. This can be attributed to the fast decrease of eigen functions of the vertical velocity upward and downward from its maximum (z_{max} = 1000 - 1200 m). At the depth 2500 m, the density of PE is almost an order of magnitude less than E_p at z_{max}.

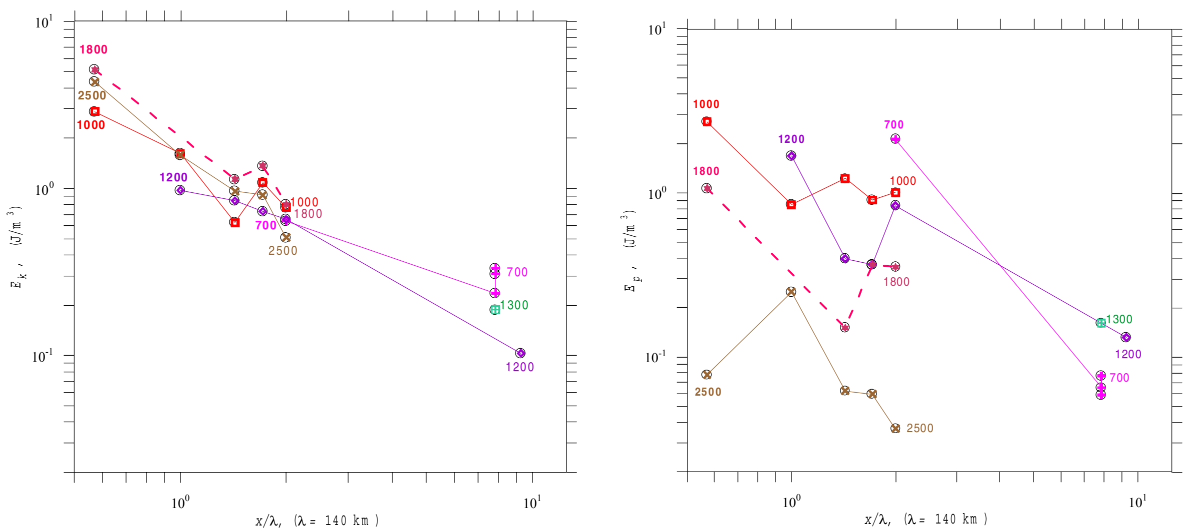

Fig. 1. The kinetic (left) and potential (right) energies downstream of the topography.

The decay of total internal wave energy E_{TW} generated by the interaction of barotropic tide with Mascarene Ridge is compared to the decay of barotropic energy E_{BT} itself (Fig. 2).

In the near zone of the ridge ($x/\lambda < 2$), $E_{TW} > (5\text{-}8)\times E_{BT}$. The ratio of baroclinic to barotropic tidal energy decreases to 1.5 - 2.1 over distances of $x/\lambda = 8$ - 10. An exponential least square approximation of the decay of E_{TW}/E_{BT} (x/λ) gives $x/\lambda = 11$ as an estimate for the distance over which the internal tide looses all of its energy (Fig. 2). The result is based on the assumption that the amount of tidal energy generated by barotropic tide in the bottom boundary layer is significantly less than the energy produced by its interaction with the ridge.

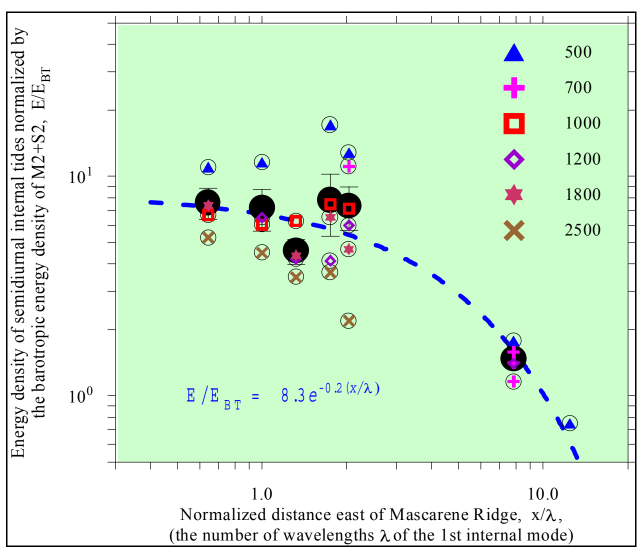

Fig. 2. The normalized internal tide energy as a function of the normalized distance from the Mascarene ridge.

B. ***Modeling of density fine structure in oceanic boundary layers***

Well-defined step-like structures are often observed in seasonal oceanic thermoclines and in the pycnoclines aloft the near-bottom mixed layer. We used *e-l* model (*e* is the turbulent kinetic energy, *l* is a Richardson number dependent turbulent length scale) with turbulent eddy-diffusivity closure to simulate oceanic conditions, and the results are consistent with field observations (Lozovatsky et al. 2000b). Periodic formation of one or two thin but prominent steps was observed in the developing pycnoclines during three-four initial cycles of inertial oscillations. The lifetime of these initial structures is less than a few hours. Later, several thin quasi-homogeneous layers merge into one "major" step that becomes a persistent feature of the mean density profile. A new series of steps are generated thereafter. The dependence of governing process in step formation on the variably of boundary stresses and background shear is examined. It was found that the period between initialization of boundary forcing and the onset of the fine structure is shorter at high latitudes compared to equatorial regions. Modeling of the layer formation in a tidal stratified flow is the novelty of our current work. One of the computational results is shown in Fig. 3.

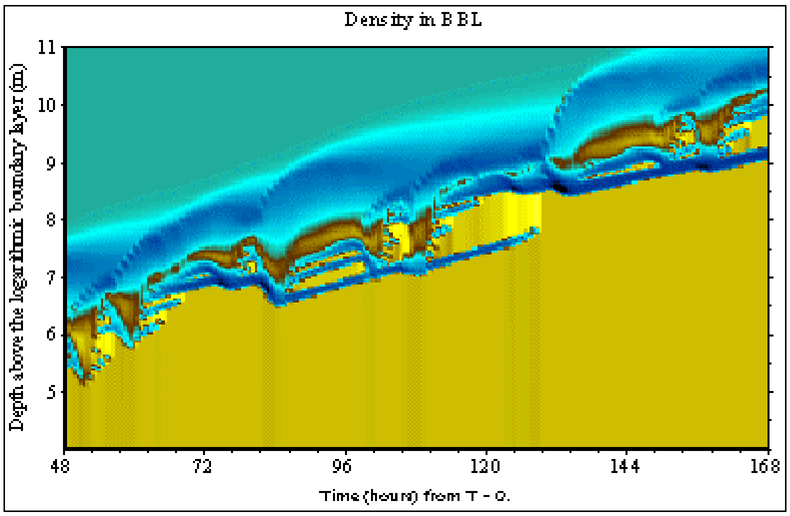

Fig. 3. The appearance of a series of fine-scale homogeneous layers and density interfaces in the near-bottom pycnocline influenced by a tidal current with semidiurnal and diurnal constituents. The initial density profile is linear with $N^2 = 2.5\times10^{-5}$ s^{-2}, and Coriolis parameter $f = 10^{-4}$ s^{-1}. The calculations are targeted to simulate the near bottom boundary layer at the West Sahara shelf.

C. ***Thermohaline mesoscale structures in the North Atlantic***

The contour plots of salinity and specific potential density sections taken along 48^0N are shown in Fig. 4. Low-saline Labrador water can be seen in the depth range 1500 - 2500 m. The core of this water contains several mesoscale "lenses" of local salinity minimum. The "lenses" are separated spatially with a horizontal lengthscale of about 220 km. It is possible that the formation of these waters has a sporadic (or periodic) nature, which is subjected to inter-annual variability.

Thermohaline inhomogeneities of hundreds meter lengthscales are usually related to synoptic eddies or meanders of large-scale circulation. Figure 4 indicates substantial influence of the topography on mesoscale dynamics in the central part of North Atlantic. A pair of anticyclonic-cyclonic topographic eddies can be associated with a trough of the density contours above the west flank of mid-Atlantic ridge and a dome of isopycnals that is slightly shifted to the east off the summit. Vertical distortions in salinity section related to these displacements can be traced up to the depths of seasonal thermohalocline. Another cyclone centered at the longitude 33^0W can be identified across the entire water column showing a low salinity spot at the sea surface and substantial stretching up of one of the "lenses" of the Labrador waters. Frontal zone between the eddies are rich in fine-structure that is generated by various process responsible for the transformation of water masses. The combined effects of mesoscale dynamics of deep ocean and stormy weather, caused by a series of atmospheric cyclones, result in a prominent horizontal patchiness of temperature and salinity in the upper quasi-homogeneous layer east of the mid-Atlantic ridge.

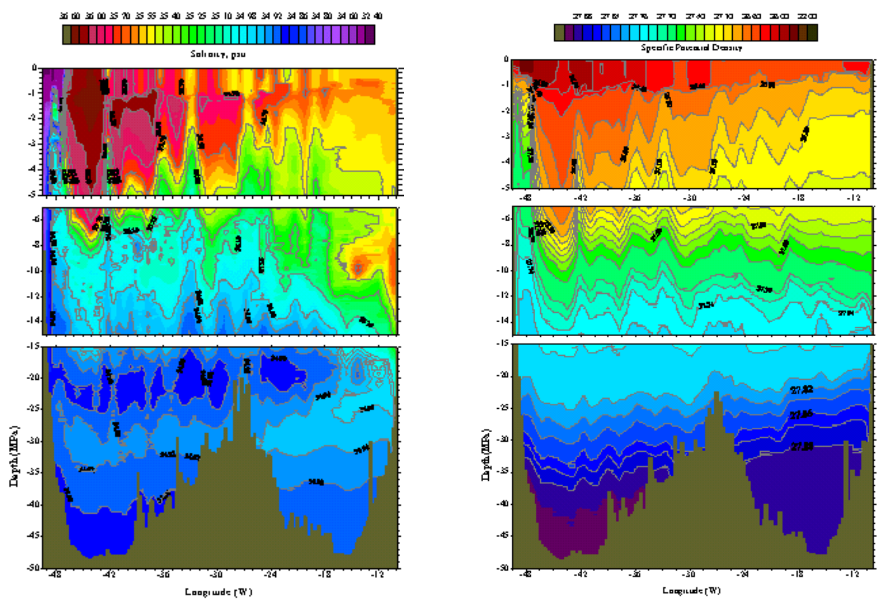

Fig. 4. Salinity (left) and specific potential density (right) contour plots along 48^0N. The data were collected in October-November 1999.

IMPACT/APPLICATION

The international oceanographic community has now access to extensive data sets obtained by Russian oceanographers and these data can be used to acquire better understanding on fine structure and internal wave dynamics of oceans, and to verify or improve numerical models. The new data collected at several trans-oceanic sections can be also used to investigate climate-related variations of meridional transport in the Atlantic.

TRANSITIONS

During this reporting period, no direct transitions were realized with the operational personnel of the Navy. The datasets are posted on the Internet for general use.

RELATED PROJECTS

The P.I. maintains contacts with Dr. Don Delisi of NWRA (Bellevue, WA) and Vadim Paka (Atlantic Branch of the P.P. Shirshov Institute of Oceanology, Kaliningrad, Russia) as a part of an ongoing project dealing with the testing of a new towing system equipped with Russian-build electro-magnetic velocity sensor.

The Co-P.I. is involved in an ONR funded project entitled "Dynamics of Cobbles Under the Action of Waves and Mean Currents" which deals with laboratory investigations on coastal waves, their breaking and interacting with solid objects.

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